Beyond the Standard Model: Proton Properties

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Abstract: We present a simple, semi-classical e-model of the proton that gives the proton mass, charge, spin and magnetic moment that are all in good agreement with measurements.

Introduction

It was demonstrated several decades ago [1] that the proton is a composite object containing point-like fundamental particles. It is now usually assumed that there are three of these point-like objects (known as quarks) and that two of them have charge $2/3e$, where e is the electron charge, and the other has charge $-1/3e$. They are somehow confined in a soup of virtual quarks and gluons. These assumptions are subject to interpretation and they have not been verified experimentally. In particular, neither quarks, gluons nor fractional charge have ever been detected directly in an experiment.

In fact, the electron and positron are the only massive, charged point-like particles that are known to exist, so in this paper we assume that the proton is composed of two positrons and one electron. We choose three components because that is the simplest possible assumption. Of course this assumption is also subject to interpretation and it has also not yet been verified experimentally, but it has some features that are more palatable than the quark model and it does lead to some natural consequences and predictions that we present in this paper.

Our assumption, then, is that the proton is composed of two positrons and one electron in an orbital structure not unlike that of a simple atom. The two positrons have relativistic orbital velocities and the electron is at rest. We refer to this model as the e-model.

In an earlier paper [2] we introduced a model of the electron that interprets the electron (and positron) as a point-like object whose mass and charge are related by a simple self-mass formula that includes both gravitational and electrostatic self-energy. Given the electron charge, in order to derive the experimentally determined electron mass we have to assume that, inside the electron, the gravitation parameter is some forty orders of magnitude larger than the well-known macroscopic value of

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G [3]. The e-model of the proton also necessitates a very large value of G inside the proton. In the following, we refer to this short distance value of G as G_0.

In the earlier paper we made the assumption that the two positrons are in the same orbit with radius $R = R_1$ and the electron is at rest at $R = 0$. The model used the measured values of proton and electron masses to obtain $R_1 = 0.8417$ fm [2].

This is a simple and attractive model but it is not supported by the experimentally determined proton charge structure shown in figure 1 (solid curve).

Therefore, in this paper we consider a slightly more complicated version of the model in which the two positrons are in separate orbits with $R = R_1$ and $R = R_2$, respectively, and the electron is at rest at $R = R_0 = 0$. We assume that Coulomb repulsion causes the two positrons to be on opposite sides of the electron.

Charge

In the conventional quark model of the proton we have to face the uncomfortable fact that the proton charge appears to be exactly equal in magnitude to the electron charge. Since electrons and quarks are unrelated particles there is no explanation of how or why the quark charges should be exactly $2/3e$ and $-1/3e$.

In our model the proton charge is, by definition, exactly the same magnitude as the electron charge so long as electron and positron have exactly equal and opposite charge, as is supported experimentally [3].

The distribution of charge inside the proton has been obtained from its electric and magnetic form factors [4, 5]. A recent particle physics planning report gives the current status based on a compilation of all available data [6]. As seen in figure 1 (solid curve), the charge is zero at the proton centre ($R = 0$), rises to a maximum at ~ 0.45 fm (1 fm = 10^{-15} m) and falls slowly to zero by ~ 2.5 fm. More than 90% of the proton charge is within a radius of 1.5 fm. The experimental uncertainty at the peak is $\sim 4\%$.

We have tested our model by attempting to fit the measured proton charge distribution of figure 1 to the sum of 3 electron charge distributions (2 positive and 1 negative). Initially we used Gaussian line shapes for the electron distributions. The fit was reasonable below about 1 fm, but the experimental charge tail above ~ 1 fm is too large to be consistent with a sum of Gaussians.

We next tried Breit-Wigner line shapes[3] and obtained an excellent description of the total proton charge distribution. The dashed curve in figure 1 shows the resulting

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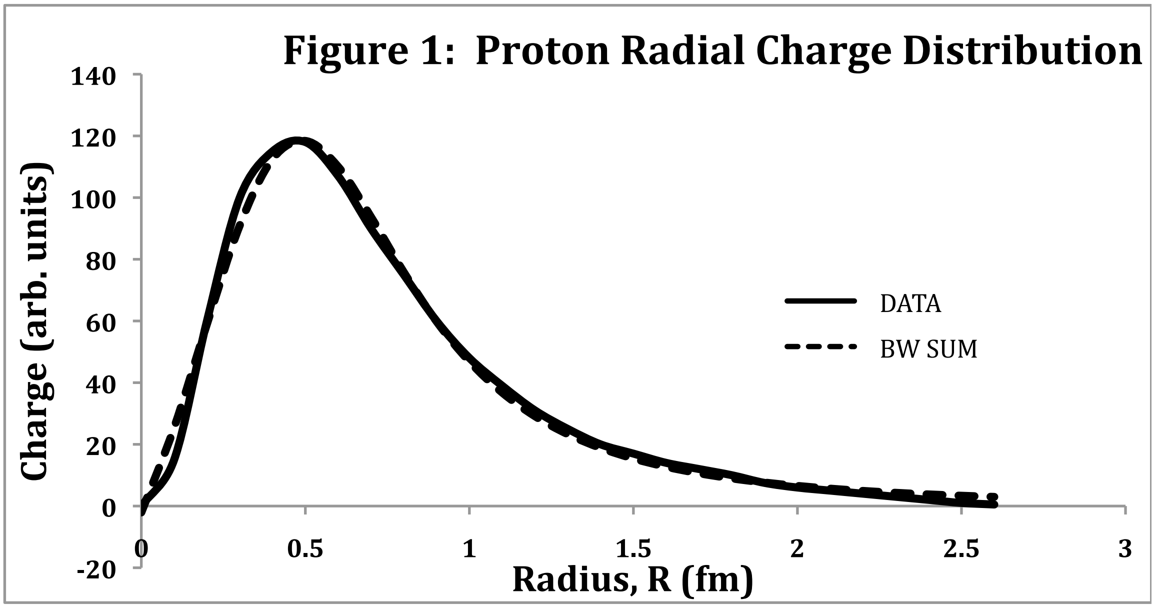
[3] $BW(R) = \frac{(\Gamma/2)^2}{(R-R_0)^2 + (\Gamma/2)^2}$ where R_0 is the central value and Γ the width.

sum of the 3 Breit-Wigners with best fit parameters: R_0 = 0 and Γ_0 = 1.20 ± 0.05 fm; R_1 = 0.35 ± 0.02 fm and Γ_1 = 0.97 ± 0.05 fm; R_2 = 0.47 ± 0.02 fm and Γ_2 = 0.93 ± 0.05 fm. We did not constrain the charge to be zero at R = 0 in any fit.



This supports the basic idea that the proton is composed of two positrons plus one electron. For calculation purposes, we assume that both positrons are at well-defined orbital radii (R_1 and R_2, respectively) and the electron is at rest at R_0 = 0. The reality is certainly more complex. It is not clear what is the significance, if any, of the Breit-Wigner line shape.

Spin

None of the components of the proton have orbital angular momentum (see the section entitled “Mass and Gravity”), so the spin of the proton is obtained by adding together the three spins. It is probably forbidden by something like the Pauli Exclusion Principle to have both positrons and the electron all with the same spin orientation inside such a small system, therefore we assume that the two positron spins cancel (one spin up, one spin down). The spin of the proton is then, by definition, exactly equal to the spin of the electron.

Magnetic Moment

In the e-model, the magnetic moment of the proton (μ_p) may be written as the sum of two terms. These are the current loop of the two orbital positrons and the mass-scaled magnetic moment (μ_e) of the central electron:

$$\mu_p = \mu_e \frac{m_e}{m_p} + IA,$$

where I is the current and A is the area of the loop.

The current loop term for each orbital positron (radius R and velocity v) may be written:

$$IA = \frac{e\pi R^2 v}{2\pi R}.$$

So, the expression for the proton magnetic moment becomes:

$$\mu_p = \mu_e \frac{m_e}{m_p} + \frac{1}{2} e(v_1 R_1 + v_2 R_2).$$

With $R_1 = R_2 = 0.4$ fm and $v_1 = v_2 = c$, $\mu_p = 14.16 \times 10^{-27}$ J/T = 2.8 nuclear magnetons; this is in good agreement with the measured value of 2.793 nuclear magnetons [3].

Mass and Gravity

We assume that the two positrons are in separate orbits with $R = R_1$ and $R = R_2$, respectively, and the electron is at rest at $R = R_0 = 0$. We assume that Coulomb repulsion causes the two positrons to be on opposite sides of the electron.

The quantum conditions for the two positrons are:

$$\gamma_1 m_e v_1 R_1 = \gamma_2 m_e v_2 R_2 = \hbar$$

where $\gamma_{1,2}$ are the relativistic factors $(1/\sqrt{1 - v_{1,2}^2/c^2})$ and $\hbar$ is the reduced Planck constant ($h/2\pi$). Note that these quantum conditions have nothing to do with angular momentum. In a semi-classical sense, they are saying that the positron de Broglie wavelength ($\lambda = h/p = h/\gamma m v$) has to equal the circumference of the orbit.

If the total internal vector momentum is zero, the effective mass of the two positrons plus one electron is:

$$m_p = m_e(1 + \gamma_1 + \gamma_2) = m_e + \hbar(\frac{1}{v_1 R_1} + \frac{1}{v_2 R_2}) .$$

The kinematic limit gives $R_1 + R_2$ = 0.8417 fm with $R_1 = R_2$. These values of R_1 and R_2 give a good description of the proton charge distribution, they give a good approximation to the measured proton magnetic moment and they give the measured proton mass exactly, assuming the measured electron mass.

For every value of $R_1 + R_2$ above 0.8417 fm, there is one solution for the positron radii that gives the measured proton mass exactly. For all of these solutions, $R_1 \neq R_2$. In fact, given the Coulomb repulsion between the two positrons one of these solutions with the two radii not quite equal might be preferred. (For example, R_1 = 0.373 fm and R_2 = 0.483 fm gives the measured proton mass.)

Since γ_1 and γ_2 are both ~ 1000, the approximation $v_1 = v_2 = c$ is good to better than 1 part in 10^6. Therefore the formula for m_p may be written:

$$m_p = m_e + \frac{\hbar}{c}\left(\frac{1}{R_1} + \frac{1}{R_2}\right).$$

The equation of motion of either positron may be used to estimate the gravitation parameter G_0. For example, for the outer positron (ignoring small terms):

$$\frac{\gamma_2 m_e v_2^2}{R_2} = \frac{G_0 \gamma_1 \gamma_2 m_e^2}{(R_1 + R_2)^2}.$$

And this gives:

$$G_0 = \frac{v_2^2 (R_1 + R_2)^2}{\gamma_1 R_2 m_e} = \frac{\hbar^2 (R_1 + R_2)^2}{\gamma_1 \gamma_2^2 R_2^3 m_e^3}.$$

At the kinematic limit $R_1 = R_2 = R$, $\gamma_1 = \gamma_2 = \gamma$, $v_1 = v_2 = v$ and $G_0 = 4\hbar^2 / \gamma^3 m_e^3 R$ = $4v^2 R / \gamma m_e$ = 1.8 x 10^{29} Nm^2/kg^2.

For all values of R_1 and R_2 consistent with the proton charge distribution and the proton magnetic moment ($R_1 + R_2 < 0.85$ fm, say) the value of G_0 is in the range 1.4 to 2.4 x 10^{29} Nm^2/kg^2.

Finally we note that in this model the proton self-mass is given by:

$$SM = m_e + \frac{G_0 \gamma_1 m_e^2}{R_1 c^2} + \frac{G_0 \gamma_2 m_e^2}{R_2 c^2} + \frac{G_0 \gamma_1 \gamma_2 m_e^2}{(R_1 + R_2) c^2} = m_e + \frac{v_1 \hbar}{R_1 c^2} + \frac{v_2 \hbar}{R_2 c^2}.$$

It is perhaps worthy of note that when $v_1 = v_2 = c$, this is exactly equal to the effective mass of the two positrons plus one electron.

Schwarzschild Radius

The Schwarzschild radius of an object of mass *m* is given by:

$$R_S = \frac{2Gm}{c^2},$$

where G is the gravitation parameter and c the speed of light *in vacuo*.

For the value of G_0 given here for the interior of the proton[4], the value of R_S = 6.7 fm. For the electron model described in [2] the value of G_0 inside the electron could be as high as 2.8 x 10^{32} Nm^2/kg^2 in which case R_S = 5.6 fm.

In both cases the Schwarzschild radius is significantly greater than the physical radius. Could this be a hint as to why both proton and electron are very stable?

Antimatter and Matter

In the Standard Model of particle physics there is a problem because there appears to be significantly more matter than antimatter in our universe. This is not a problem with the e-model discussed in this paper. In a charge-neutral universe there are an equal number of electrons and positrons. If the electron is matter, then the positron is antimatter and *vice versa*. The fundamental matter-antimatter balance is between positive and negative electrons. All other particles are composite objects containing some matter and some antimatter. The neutron and all atoms contain an equal quantity of matter and antimatter. By definition, there is no matter-antimatter asymmetry.

Conclusions and Predictions

In this paper we introduce the e-model of the proton that takes us beyond the Standard Model. The proton is assumed to be composed of an electron and two positrons that are completely contained in a sphere of radius ~ 2.5 fm. They are assumed to be at radii of zero, R_1 and R_2, respectively and are held together by gravitational forces with a gravitation parameter G_0 that is approximately forty orders of magnitude larger than the macroscopic value. All of the measured proton properties are consistent with the calculated quantities provided by this model.

There is no acceptable quantum theory that governs this situation and so our calculations are made within a simple, semi-classical framework.

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[4] We are making the assumption that G is dominated by its short distance value G_0. The same is true of the formula for self-mass in the previous section.

It is remarkable that such a simple model can calculate the exact proton mass and magnetic moment, charge and spin that are all in excellent agreement with measured values. However, it is interesting that the charge distribution and the magnetic moment both prefer $R_1 + R_2 \sim 0.8$ fm whereas the proton mass calculation requires $R_1 + R_2 \geq 0.8417$ fm, where R_1 and R_2 are the positron orbital radii. This might be a clue or it might be simply reflecting the approximate nature of the model.

Indeed, we are not suggesting that this is an exact description of the proton. It is, at best, a good approximation that might lead us in the right direction. The results of the calculations indicate that we might be on the right track.

Two other interesting features of the e-model are a natural matter-antimatter symmetry in the universe and a hint of a *rationale* for the stability of the electron and the proton.

If the model does have some validity, then we can make some predictions that ought to be testable in well-designed experiments. These have been discussed elsewhere [2]. Two of them are worth repeating here:

- The gravitation parameter has to drop from $\sim 10^{29}$ Nm^2/kg^2 to $\sim 10^{-11}$ Nm^2/kg^2 as distances increase from $\sim 10^{-15}$ m to $\sim 10^{-2}$ m. This should be detectable;
- It should be possible to produce single protons and single antiprotons in e^+e^- collisions via the reactions $e^+e^- \to pe^-$ and $e^+e^- \to \bar{p}e^+$. An e^+e^-experiment below the $p\bar{p}$ threshold (at 1.85 GeV, say) ought to produce detectable ~ 700 MeV/c protons and antiprotons.

Acknowledgements

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We also thank Chris Johnson for useful comments and for running a cross-check of the proton charge distribution fits.

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